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MINI-REVIEW

Minimally invasive cardiac surgery

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Summary Cardiopulmonary bypass surgery was invented in 1953. Since then, cardiac surgery has had a prosperous age for several decades. The introduction and evolution of percutaneous coronary intervention, however, was a great challenge to traditional coronary revascularization, one major part of cardiac surgical practices. In fact, the adoption of endoscopic techniques fundamentally changed several surgical disciplines. For the past 10 years, the concept and practice of minimally invasive cardiac surgery has gradually grown in popularity. The growth has been driven by multiple factors. From the patients' point of view, less surgical trauma, a higher margin of benefit/cost ratio, and speedy recovery to normalcy are all desirable. The outlook of less invasive incisions is well elucidated by the general population. From the surgeons' point of view, the adoption and evolution of new techniques and technologies fulfill the learning prospect of the profession, excel to excellence, and may contribute to the patient's welfare. From the viewpoints of health industries, new practices imply new innovation, investment, and business. However, surgeons face obstacles to the development of less invasive approaches. Initiatives are hindered by limited surgical exposure, unfamiliar environments, prolonged operative time, unexpected troubleshooting, etc. Nevertheless, with enabling technologies, refined instruments, and pioneers' lead, cardiac surgery is now heading toward less invasive approaches. More and more cardiac surgeons adopt these techniques and more and more evidence demonstrates the benefits of these approaches. In this article, several update approaches are reviewed.

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1. Introduction

Cardiac surgery, as other specialties has move toward less invasiveness. Although there comes alternatives like percutaneous valve repair or replacement technology, the majority of valve disease patients will probably not benefit from them so soon. Because heart-lung machine is still needed, the efforts in less invasive cardiac surgery has focused on reducing surgical trauma by downsizing the incisions. In the following paragraphs regarding minimally invasive cardiac surgery, we will discuss: mitral valve, aortic valve, coronary artery revascularization, and hybrid approaches.

2. Minimally invasive mitral valve surgery

Mitral valve surgery has been the procedure most greatly influenced by minimally invasive approaches. Several pioneers, like Navia and Cosgrove,[1] Cohn et al,[2] Chitwood et al,[3] and Carpentier et al[4] independently described minimally invasive mitral valve surgery after mid-1990. Those operations were performed through parasternal, hemisternotomy, and minithoracotomy approaches. The most popular approach for minimally invasive mitral valve surgery in current practice is through a right minithoracotomy.

In addition to routine preoperative studies for conventional surgery, minimally invasive approaches are concerned more with local anatomy and systemic comorbidities. Morbid obesity, suggestive evidence of right pleural adhesion, reasons precluding one lung ventilation, funnel chest, and aortoiliac disease are relative contraindications for minithoracotomy mitral valve surgery. Computed tomography to reveal chest anatomy, and to exclude significant ascending aortic calcification and aortoiliac disease, is helpful. The induction of anesthesia is the same as with conventional operations. Double-lumen endotracheal intubation offers one lung ventilation during the procedure. A central venous catheter is usually inserted through the left neck to reserve the right neck for potential superior vena cava cannulation. The patient is put in a left decubitus position with a small pillow under the right shoulder. The right upper extremity is usually put aside on the table to maximize the exposure of the right lateral chest. The external pads for cardioversion are routinely employed. Transesophageal echocardiography is extremely helpful to verify the pathology, and in the deairing process, and completion of the proper operation.

Peripheral cannulation is usually required to further reduce the chest incision and maximize the operative space. Femoral vessel cannulation using the puncture method and Seldinger's technique is common practice. For better drainage and reduction of intracardiac residual blood, vacuum-assisted venous drainage is frequently employed. Superior vena cava cannulation via the right internal jugular vein is applied for better drainage or exclusion of both venae cavae during the right heart procedures. Although the heart locates mostly in a left deviated position, right thoracotomy is the incision of choice for easier exposure, better visualization, and the ease of aortic manipulation. The chest incision usually locates along the breast contour or pectoralis major muscle margin and is made more laterally to the right nipple for better cosmesis. The right pleural cavity is usually entered via the fourth intercostal space. Aortic cross-clamping can be achieved by an endoaortic clamp or transthoracic clamp. The transthoracic clamp has the advantages of less expense, and easier manipulation and reproducibility at the expense of one additional chest stab incision. Cardioplegic arrest is critical for small-incision procedures. Repetitive administration of cardioplegic solution is usually required for potentially prolonged procedures. Aortic root venting catheters, miniports,[5] and pigtail catheters[6] can be used for this purpose. They also provide the advantage of deairing after the completion of intracardiac procedures. Application of carbon dioxide in the operative field has been common practice. It enhances the dissolution and reduces the risk of air embolism. Exposure of the mitral valve requires specialized instruments. Most of these need assembly inside the pleural cavity. Inside the pleural cavity, the surgeon sees the details by direct vision or through the endoscope. Direct vision implies larger incision and the use of a rib retractor, which may increase postoperative pain. An endoscope has the advantages of magnification and video broadcasting. It requires an additional port and enables the cardiac surgery through a slit intercostal incision, a so-called non-rib spreading approach. Both repair and replacement techniques are similar to conventional concepts founded by Carpentier, but through extended length instruments.[4]

The hypothesized benefits of minimally invasive mitral surgery consist of decreased length of stay, decreased surgical trauma, reduced pain, improved patient satisfaction, and potentially reduced hospital resource utilization. These advantages, however, have often been challenged by increased operative times, decreased surgical exposure, and a significant learning curve. However, over the past 10 years, more outcome articles have been published in the literature. No studies to date have demonstrated a significant difference in mortality rates between minimally invasive and sternotomy mitral valve surgery.[7–9] At our hospital, we have observed better outcomes in mean postoperative ventilation time and mortality rates between sternotomy and minithoracotomy mitral valve surgery. The Society of Thoracic Surgeons database showed that, after risk adjustment, there was a lower probability of postoperative atrial fibrillation,[10] perioperative red blood cell and platelet transfusion, and overall major morbidity or mortality. However, stroke was more common among less-invasive mitral valve surgery patients.[9] This increased risk of stroke was attributed to potentially inadequate deairing, fibrillating-heart techniques, prolonged cardiopulmonary bypass, cross-clamp times, and a retrograde perfusion strategy.[11–13] Within our hospital this was not shown, which might be attributed to adherence to standard operative procedures and smooth passage of the learning curve. Overall, the majority of the papers reporting on comparative safety suggest that minimally invasive mitral valve surgery is at least as effective as the sternotomy approach across most perioperative complications.[14,15] In addition to safety, decreased intensive care unit (ICU) stay, decreased hospital stay, decreased postoperative pain, improved patient satisfaction, faster return to normal physical activities, and improved overall quality of life have been demonstrated.[16–18] For certain patient groups, such as those with obesity,[19] reoperation,[20,21] chronic obstructive pulmonary disease,[22] and those including elderly patients,[23] the minimally invasive procedure has been shown to be beneficial.

Cost-effective analysis also showed favorable results.[24] With regard to long-term outcomes, no published studies have demonstrated significant differences in freedom from reoperation, differences in degree of postoperative mitral regurgitation, or differences in long-term survival between sternotomy and minimally invasive approaches.[8,18] Nevertheless, the application of these outcome studies depends on the surgeon and institutional experience, and patient selection. The benefits are likely to be achieved in relatively high-volume centers. Minimally invasive mitral surgery remains a challenge, because of its significant learning curve, and may be a problem in patients with specific risk factors, such as obesity, prior cardiothoracic surgery, aortoiliac diseases, and pulmonary diseases.

In 1998, the Leipzig group described port-access mitral valve surgery with voice-activated robotic assistance.[25] Carpentier et al[26] described the first completely robotic mitral valve repair using the Da Vinci Surgical System (Intuitive Surgical, Inc., Sunnyvale, CA, USA). By 2006, 1700 robotic operations had been performed, representing approximately seven cardiac operations per year for each Da Vinci robot in the United States.[27] The vast majority of robotic procedures were used primarily for harvesting the left internal mammary artery. The operative times for robotic mitral valve surgery are greater than for a traditional sternotomy approach, or minimally invasive mitral valve surgery. To be familiar with minimally invasive mitral valve surgery, by both console and bedside surgeons, will be beneficial for them to conduct robotic mitral valve surgery. With further refinement of the robotic design and surgeons' skill, robotic mitral valve surgery will continue to be an option for patients in the future; however, widespread adoption of this technique continues to face challenges.

3. Minimally invasive aortic valve surgery

Numerous alternative incisions were evaluated for minimally invasive aortic valve surgery. Cosgrove and Sabik[28] performed mitral and aortic valve surgeries with a right parasternal incision, which necessitated resection of the third and fourth costal cartilages and resulted in potential chest wall instability. Some modifications in our hospital eliminated the need to resect the rib cartilages and preserved the integrity of the thoracic cage. Therefore, the parasternal approach becomes the procedure of choice for our aortic valve surgery and also multiple valve procedures. However, the most common approach used is the ministernotomy, using a J, inverted T, or other similar incision.[29] Other incisions have been used in a right thoracotomy and trans-sternal approach.[2]

Our parasternal incision is made one-finger breadth lateral to the right sternal border. After muscle sparing dissection, the third and fourth sternochondral junctions are transected and the myocostal flap is bent into the right pleural cavity to create a window for further operation. Peripheral cannulation is mentioned earlier in this communication. After exclusion of both venae cavae, a right heart procedure can be performed. Through Waterston's groove or interatrial septum, a mitral valve procedure could be performed as well.

Most studies have failed to show significant differences in morbidity or mortality between minimally invasive aortic valve replacement (AVR) and conventional operations.[29–31] In fact, minimally invasive AVR is more frequently associated with improvements in postoperative outcomes, including reduced intensive care unit stay, postoperative ventilator support, hospital stay,[30,31] and earlier return to work and to normal activity.[2] Blood transfusion rates were shown to be similar or lower in minimally invasive surgical patients.[30,32]

Surgical AVR, whether utilizing traditional or minimally invasive techniques, has an overall low operative mortality[33]; however, the mortality rate increases considerably with additional comorbidities. Transcatheter AVR was developed for patients with severe symptomatic aortic stenosis who are not eligible for surgical aortic valve replacement.[34] Both the CoreValve (Medtronic, Minneapolis, MN, USA) and Edwards Sapien valves (Edwards Lifesciences, Irvine, CA, USA) have received approval for use in Europe, and the CoreValve is still under investigation in the United States. The number of these practices has grown significantly in just a few years and early published data have been promising. A multicenter, randomized trial, Placement of Aortic Transcatheter Valve (PARTNER), has completed enrollment. The trial included patients with severe symptomatic aortic stenosis who were poor or unsuitable surgical candidates. Its two treatment arms included an arm comparing outcomes of optimal medical management (including balloon valvuloplasty) with transfemoral AVR in patients considered "inoperable" (Cohort B) and an arm comparing outcomes of traditional surgical AVR with transfemoral AVR or transapical AVR in high-risk patients (Cohort A). Data from cohort B demonstrated a significant reduction of all-cause mortality and a significant increase in the incidence of cerebrovascular accidents and other major vascular events associated with the transfemoral AVR.[35] Currently available cohort A data demonstrated that the study achieved its primary endpoint at 1 year, concluding that survival of patients treated with the Edwards Sapien transcatheter aortic valve was equivalent to the survival of those treated with surgical AVR. The final results of this trial will play a major part in determining the role of transcatheter AVR in the future. Continuous evolution of this technique potentially alters the market share of minimally invasive treatment options. More evidence will be needed to address the durability and long-term efficacy.

4. Minimally invasive coronary revascularization

For more than 4 decades, coronary artery bypass grafting (CABG), consisting of full sternotomy, cardiopulmonary bypass, and cardioplegic arrest, has been the gold standard for revascularization in multivessel coronary artery disease. Off-pump coronary artery bypass (OPCAB) surgery has demonstrated comparable results in selected patients and has been widely adopted. Although coronary artery bypass surgery offers survival advantages and reduces symptoms for patients with multivessel disease, perioperative risks including mortality, cerebrovascular accident, need for transfusion, atrial fibrillation, and neurocognitive dysfunction, remain concerns for patients with suitable indications. With the same ideas to improve CABG outcomes and to decrease patient recovery time, minimally invasive approaches for coronary revascularization have been introduced. Evolving approaches aimed at reducing complications and providing a safer, less intrusive journey of CABG are subsequently described. However, considering the facts that complete revascularization is the cornerstone of coronary revascularization, the harvest of both internal mammary arteries offers better long-term outcomes, and extensive use of percutaneous coronary intervention is popular, the application of minimally invasive coronary revascularization is actually limited to small shares.

The minimally invasive direct coronary artery bypass (MIDCAB) procedure was introduced into the surgical literature in 1995. The MIDCAB was usually performed through anterolateral thoracotomy, harvesting the left internal mammary artery and constructing anastomosis to the left anterior descending coronary artery without cardiopulmonary bypass, also referred to one type of OPCAB.[36] OPCAB can be applied to thoracotomy or traditional full sternotomy procedures. The International Society for Minimally Invasive Cardiothoracic Surgery has published several recommendations regarding OPCAB versus traditional on-pump CABG. The employment of OPCAB is recommended to reduce perioperative morbidity, to reduce neurocognitive dysfunction, and to reduce hospital stay, especially in high-risk patients, including patients with severe aortic calcification of the ascending aorta, liver cirrhosis, and renal insufficiency, in order to reduce morbidity and mortality.[37] From the real world practice, most surgeons agree that the outcomes of either on-pump CABG or OPCAB depend more on the experience and quality of the particular surgeon and institution, rather than the specific on- or off-pump techniques used.

Multivessel revascularization through left anterior thoracotomy is feasible. The use of a 5–6 cm left lateral thoracotomy for the left internal mammary artery harvest and coronary revascularization, with a mean of 2.9 ± 1.1 grafts performed via this incision, has been reported.[38] In our 10-year OPCAB series, 20% of patients underwent sternum-sparing thoracotomy for revascularization. They received 1.95 grafts per patient. Using composite grafts (internal mammary artery, radial artery, or saphenous vein) or additional saphenous vein grafts (from axillary artery or descending aorta) provides complete revascularization through left anterior small thoracotomy in the OPCAB manner.

It has also been shown that OPCAB via thoracotomy can be performed safely when utilized for repeat revascularization.[39] Again, a sternum-sparing incision reduces chest trauma, with the similar potential to result in decreased postoperative length of hospital stay, improved cosmetic results, faster recovery, and reduced transfusion requirements.[40] Long-term graft patency for MIDCAB has been shown in excellent quality.[41]

There have been growing documents regarding the safety and feasibility of coronary revascularization procedures accomplished via robotic assistance. These reports include the robotic left internal mammary artery harvest followed by an on-pump MIDCAB, off-pump MIDCAB, on-pump totally endoscopic coronary artery bypass (TECAB), or off-pump TECAB.[42] Currently, robotically assisted CABG mainly focuses on the left internal mammary harvest. The other applications are still restricted by resource consumption, technique demanding, and incomplete revascularization. It is difficult to foresee the widespread use of this technology.[43]

5. Hybrid therapies

Hybrid coronary revascularization is a relatively new idea that provides patients with an alternative to full sternotomy CABG by applying a MIDCAB with stenting of other occluded coronary arteries. These two interventions can be performed simultaneously or in sequences. It has the advantage of left internal mammary artery to left anterior descending artery anastomosis which is the best revascularization strategy for this territory.[44] This approach may gain more acceptance from patients demanding complete revascularization, but refusing full sternotomy. However, it also carries the intrinsic disadvantages of the two components: surgical trauma and, more importantly, repeat revascularization after percutaneous coronary interventions. Hybrid revascularization is currently used mostly for patients with high surgical risks.[44] Some conflicting perioperative management and high costs associated with the procedures remain controversial issues.[45] Other hybrid therapies include minimally invasive valve surgery combined with percutaneous coronary intervention. In this context, full sternotomy combined operations could be transformed to a less invasive, minimal access valve surgery.[44,46]

6. Conclusion

Since minimally invasive cardiac surgery was introduced, there has been a significant expansion in popularity and experience.[47] Various techniques for obtaining appropriate exposure have been developed and put into practice. Regardless of the variety of surgical approaches, the overall objectives of minimally invasive cardiac surgery remain constant, in order to provide a safe and effective approach with the benefits associated with minimal access surgery. As with many surgical techniques, patients with particular risks are better candidates for certain techniques. A patient-centered approach for the selection of different approaches must be implemented. Meanwhile, the surgeon should always take the capability of himself, team members, and the institute into consideration. Although the difficult learning curve of minimally invasive cardiac surgery has been discussed, the central concepts to adopt new techniques and technologies should always include the initial selection of uncomplicated patients, the buildup of a consistent operative team, and following modular and stepwise approaches in order to increase complexity and reduce the skin incision. More and more evidence supports the notion that minimally invasive cardiac surgery is feasible and reproducible. A greater number of requests for minimally invasive cardiac surgery by patients seems inevitable. It should not only be the alternative to conventional cardiac surgery, but also the standard of care in experienced hands.

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